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UTILITY FUNCTIONS IN READINESS MEASUREMENT USING AN INTERVIEW APPROACH

Norman N. Barish, et al

New York University

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13. ABSTRACT

Risk and uncertainty are dominant features in readiness study and the attitudes of Navy commanders and decision-makers towards these risks and uncertainties are important considerations in any readiness measurement and reporting system. The first section of this report describes with a simple example how different observers can arrive at different estimates of a unit's readiness given the same basic data. The second section classifies individual attitudes towards risk and uncertainty in a utility framework. The third section suggests procedures for interviewing Navy commanders to approximate their attitudes using utility functions. Some practical aspects are then discussed.

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Utility Functions in Readiness Measurement

Using An Interview Approach

ABSTRACT

Risk and uncertainty are dominant features in readiness study and the attitude of Navy commanders and decision-makers towards these risks and uncertainties are important considerations in any readiness measurement and reporting system. The first section of this report describes with a simple example how different observers can arrive at different estimates of a unit's readiness given the same basic data. The second section classifies individual attitudes towards risk and uncertainty in a utility framework. The third section suggests procedures for interviewing Navy commanders to approximate their attitudes using utility functions. Some practical aspects are then discussed.

Key Words: Readiness, Utility functions, Risk and Uncertainty

INTRODUCTION

Evaluation of current and future military resources and weapon systems as well as of potential enemies and their capabilities, plans and intentions are all surrounded by risk and uncertainty. Risk and uncertainty are thus dominant features in readiness study and the attitudes of Navy commanders and decision-makers towards these risks and uncertainties are important considerations in any readiness measurement and reporting system.

Researchers working over the past decade on the problem of readiness measurement have implicitly assumed the existence of a specific readiness value or set of values for a Navy unit or set of units, measurable by procedures which were formulated by these researchers. It was implicitly assumed that all observers of the unit who had identical information concerning its resources and their states, would agree upon these readiness values. It was not assumed that one's readiness evaluation could be affected by any personal behavioral characteristics of the evaluator and that perhaps readiness measurement depends to some extent on the person making the evaluation. The present report is directed to showing that a readiness estimate may be significantly affected by any evaluator's attitudes towards risk and uncertainty.

The first section of this report describes with a simple example how different observers can arrive at different estimates of a unit's readiness, given the same basic data. The next section classifies individual attitudes towards risk and uncertainty in a utility framework. The third section suggests procedures for interviewing Navy commanders to approximate their attitudes using utility functions. Some of the practical aspects of the methodology are then discussed.

The interview procedures proposed in this report for approximating a commander's utility function must refer to hypothetical situations, no matter how great an effort is made to make them realistic. Therefore, a need exists to develop models which will use actual readiness evaluation decisions to estimate the commander's utility function. The additional possibilities and problems of such models are explored in a separate technical report.

RISK IN READINESS MEASUREMENT

To initiate our discussion, let us consider an example where an enemy attack against a group of ships is contemplated and the uncertainties relate to defense against varying possibilities for the size of the attack, which is unknown. The commander of the group has known amounts of various resources available to meet the attack (manpower, weaponry, aircraft, etc.). The question to be answered is, not knowing the specific type of attack that will occur, how does he go about estimating the group's readiness? Obviously, the group is usually "more ready" for a low level attack than it is for a heavy attack.

Let us use a cardinal valued unidimensional measure of effectiveness of mission performance which will be called level of mission performance and can range from zero to one. Let R equal this level of performance. Now suppose that a value of 0.9 represents the consensus of what most commanders would represent as a most likely or normal result based on the available resources and the estimated probabilities of various threats or levels of attack. Values greater than 0.9 represent more favorable than expected results, whereas values less than 0.9 represent less favorable than expected results.

Let us assume that all commanders have roughly the same attitude or feeling towards the 0.9 result, and therefore in terms of a utility function, a utility value of zero is associated with all individuals if the 0.9 result occurs. Now suppose it is concluded that the only possibilities that can occur, based on intelligence about the enemy intentions, are values of $R = 0.6$, 0.9, and 1.0. Consensus estimates of the probabilities for each (subjective) are 0.2, 0.5, and 0.3 respectively. Now consider the estimate as to the group's readiness of two classes of commanders whom we shall designate as type A and type B.

Commanders of type A feel that a level of $R = 0.6$ will be catastrophic whereas type B commanders feel that such a result would be much less serious. Both attitudes toward $R = 1.0$ are quite favorable, more or less about the same. Such attitudes, as represented by a utility curve, might appear as shown below:

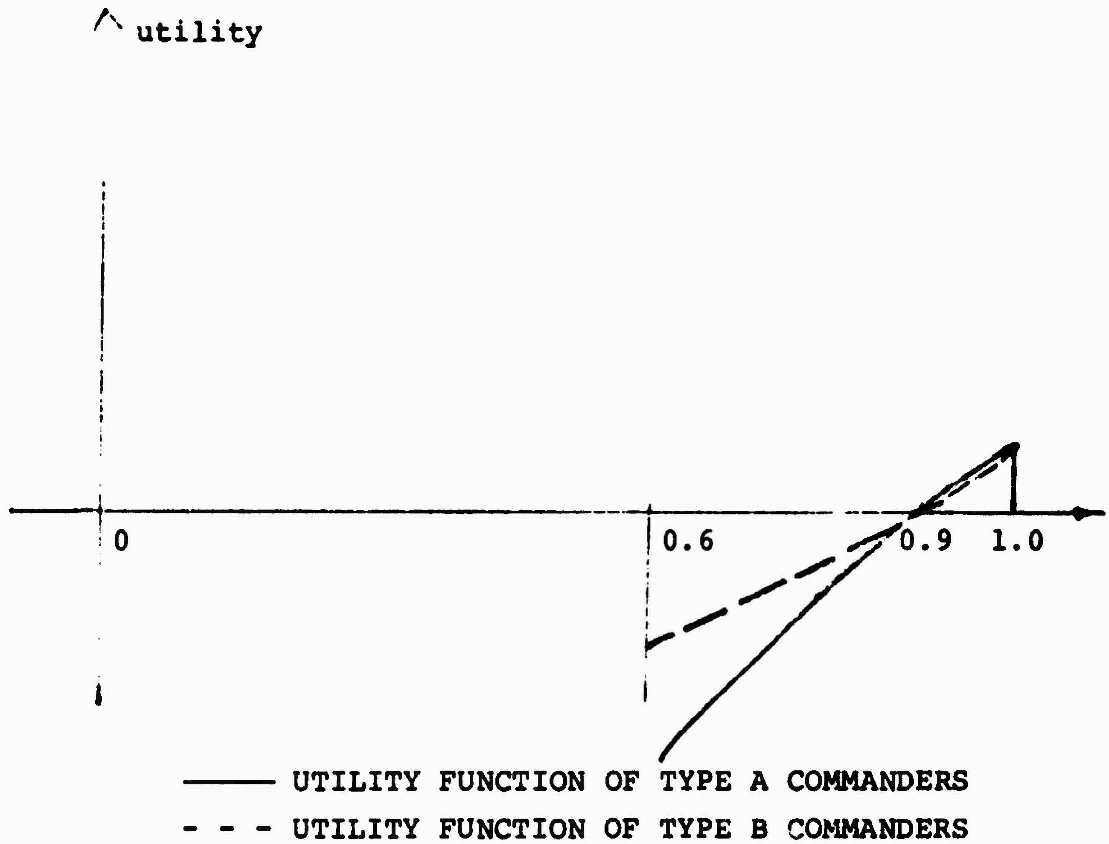

Figure 1: Two Possible Utility Functions Relating to Mission Outcome

There are various manners in which individual commanders of Type A or Type B would evaluate their readiness in the above situation. For example, some might feel that readiness represents the potential effectiveness of the unit in the event the worst possible situation occurred. Obviously, if one felt this way, he would consider only the utility associated with $R = 0.6$. In such an approach, the magnitudes of the probabilities associated with $R = 0.6$ will also most likely be involved since a commander might not consider the occurrence of such an event very likely if its probability of occurrence was, let us say, less than 0.1. If the worst possible outcome were the only one considered, the utilities for all other possibilities as well as their probabilities would be ignored, and the utility function for such individuals, insofar as estimating readiness is concerned, would not have the above shape but rather that shown in Fig. 2 which is discussed shortly.

If both commanders, however, considered all the possible outcomes in evaluating their readiness, then a conceptual normative model which may relate to the manner in which they make decisions involves computing their expected utility and equating this with their readiness evaluation. That is, if we computed a quantity $U = \sum_j p(j)u(j)$, where j = the possible values of $R(\sum_j p(j) = 1)$, and use this as a readiness evaluation, our model would tell us that A would perceive that the group was less ready than would B. A's utility curve is one of decreasing marginal utility whereas B's has increasing marginal utility. A would be considered to be a more risk-averse individual than B. The expected utility hypothesis is one possible model for explaining behavior although it should be kept in mind that people do not compute and evaluate their own utilities to make decisions.

It should be emphasized that in the methods so far considered, there is no disagreement among decision-makers as to the value of R if any of the events with the designated probabilities occurred with certainty. The differences in perceived readiness will occur because of the manner in which different individuals assess the possible outcomes when risk and uncertainty do exist.

Another possibility, illustrating a different type of utility function, might be associated with commander C who considers that any result where $R \geq 0.89$ is equally acceptable but that any result where $R < 0.89$ is equally unacceptable. Such an attitude can be described by a utility function of the form shown in Fig. 2.

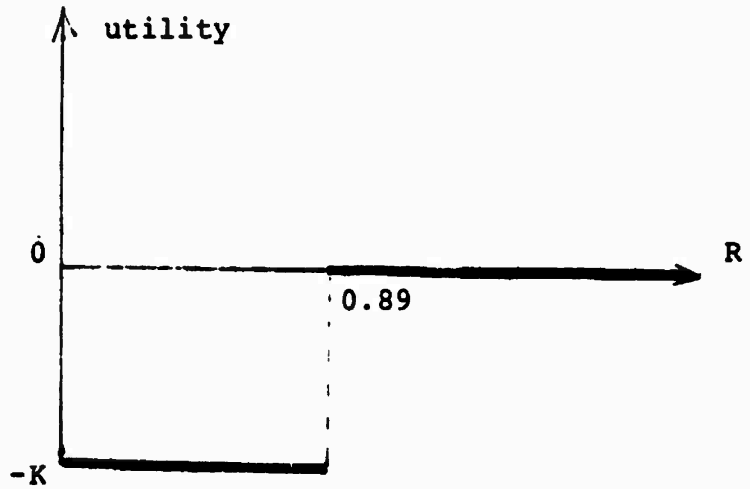

Figure 2: Another Possible Utility Function for Mission Outcome

The expected utility for such an individual is given by $-K\ \mathrm{Prob}\{R \leq 0.89\}$. If such expected utility is associated with readiness then the readiness is governed only by the probabilities of those events which will have results of $R \leq 0.89$. In our example $\mathrm{Prob}\{R \leq 0.89\} = 0.2$, since there is only one event where $R \leq 0.89$. The above type of utility function can be associated with individuals who consider only the worst possible outcome. The actual utility function for these persons is one having some negative value at the worst value of R and zero values everywhere else.

From the above discussion, it appears that some more detailed study of how Navy attitudes towards risk and uncertainty affect readiness measurement may be appropriate in order to better understand the readiness measurement problem. This part of the research need not become involved in any actual numerical approximations to utility functions.

CLASSIFICATION OF ATTITUDES TOWARDS RISK AND UNCERTAINTY

Although utility functions could be classified in various different ways, we shall define some broad types which may be useful in helping to describe possible behavior with regard to readiness expectations for Navy missions. We will consider utility with respect to only a single variate although later we will discuss why a consideration of multivariate utility functions may be appropriate.

Since utility functions for practically all individuals will be monotone non-decreasing (more favorable outcomes will be preferred to less favorable ones), an initial classification can be made on the basis of whether or not the functions have the same concavity or convexity properties throughout their ranges of definition. Let us call those functions which are either (1) strictly concave, (2) strictly convex, or (3) linear, strictly as belonging to class A, and those which do not have such properties as being in class B. Thus, class A contains the following three type functions, subclassified as A_1, A_2, and A_3 respectively, as indicated in the following figure. In utility terms A_1 type curves are associated with decision-makers who perceive that an outcome X with certainty is preferred over a chance outcome which might be $X + \alpha$ with probability = 0.5, or $X - \alpha$ with probability = 0.5. Type A_2 curves are associated with individuals who would not prefer X with certainty over the chance outcome in the example below. Finally, individuals with type A_3 curves consider that they act in such a manner as to maximize their expected gain, and hence would be indifferent between the above two alternatives.

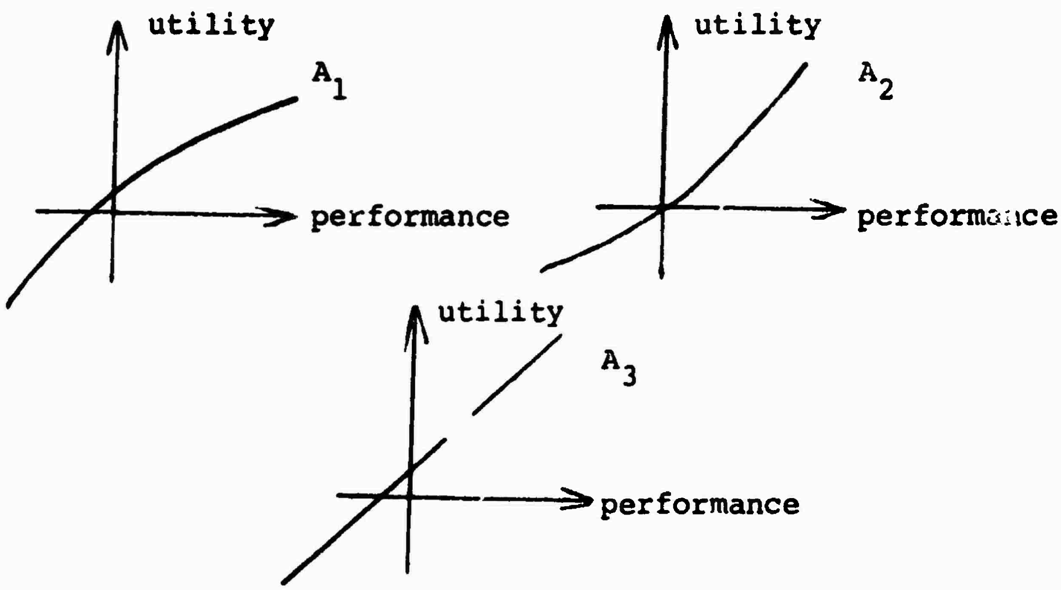

Figure 3: Class A Utility Functions

Note that in any situation where an individual is making decisions for an organization, military or otherwise, there may be conflict between the utility value for himself as an individual as opposed to that of the organization. Thus, it may be possible that the alternative which maximizes expected utility for the individual (if he acts in his own self-interest) may be different than the alternative which maximizes expected utility for the organization. However, often the long-range interests of the individual and the organizations will usually coincide in some further detail.

Another important point to keep in mind regarding these curves is that the range of values on the abscissa are those within the ordinary range of allowable decisions of the commander.

Regarding utility functions of class B, there is obviously a variety of types which one might consider. However, for military type applications, there seem to be two general shapes which may correspond to the perception of many decision-makers. The first (called B_1) widely discussed in the literature [1] has the shape shown in the figure below:

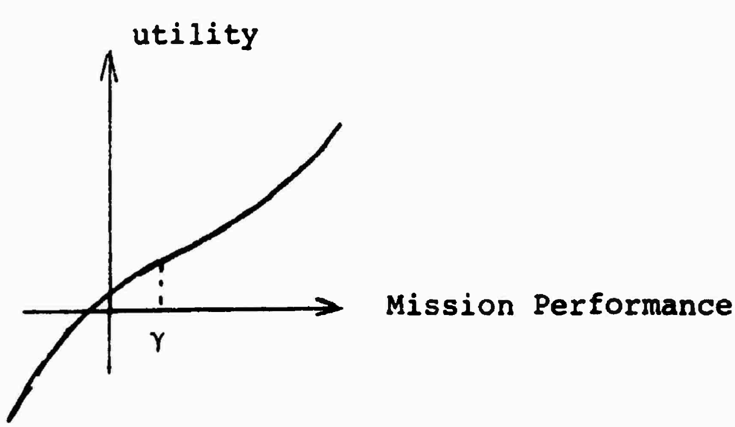

Figure 4: Class B_1 Utility Function

Type B curves are convex for mission outcomes less than some value γ and concave for all outcomes $\geq \gamma$. Such curves may represent the behavior of individuals who feel that the

Navy is basically risk-averse for undesirable consequences (outcomes having values $R < \gamma$) but who may feel that the Navy is not risk-averse when more desirable consequences are involved. For example if the outcomes of a particular mission represent "number of enemy aircraft lost minus the number of our own aircraft lost," then the commander may feel that the Navy would prefer the chance outcome "fifty-fifty chance of a net positive difference of either forty or twenty" over the outcome "net positive difference of thirty with certainty." However, he may also perceive that the Navy would prefer a net negative difference of ten with certainty over a fifty-fifty chance of a net negative difference of thirty or a net positive difference of ten.

Another type of possible function (type B_2) which may be a possible manner in which some commanders view the Navy's utility preferences is shown below:

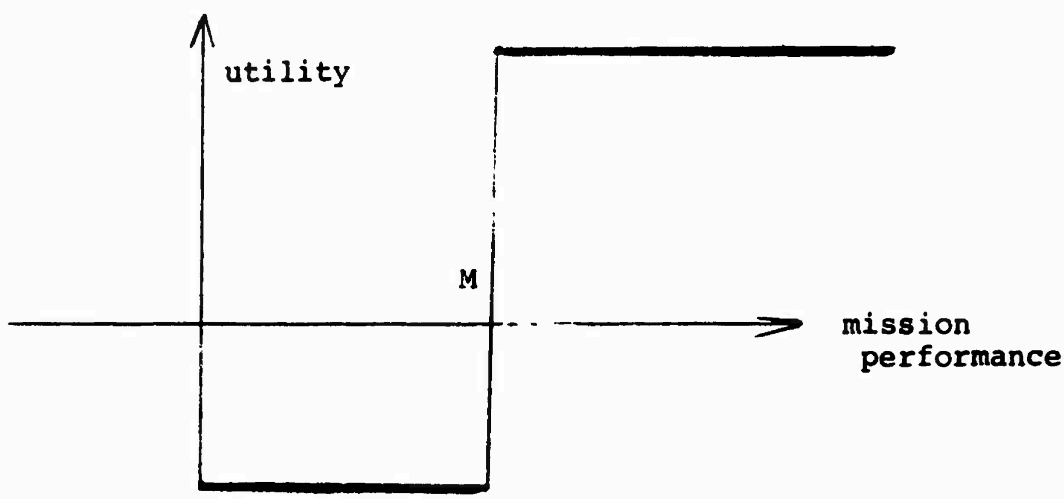

Fig. 5: Class B_2 Utility Function

Here (a special case of which was discussed previously) all outcomes greater than some value M are equally preferred while all outcomes less than M are considered to be equally undesirable. This might describe a situation where it is felt that in order for a mission to be successful, at least M must be accomplished – anything less is equivalent to failure. For example, unless at least M percent of an enemy's industrial capacity were destroyed the enemy's productive facilities could recover sufficiently fast to make a massive attack ineffective. If at least M percent of its capacity were destroyed (it is felt), recovery would be next to impossible.

Variations of this type of utility function could involve more than one step. For example, the enemy's productive capacity might be dealt a severe, but not disastrous, blow if at least $M_1 < M$ percent of its productive capacity was destroyed, and then the possibility of recovery goes to zero as the percent of capacity destruction rises to M. The utility function representing this situation might appear as in Figure 6.

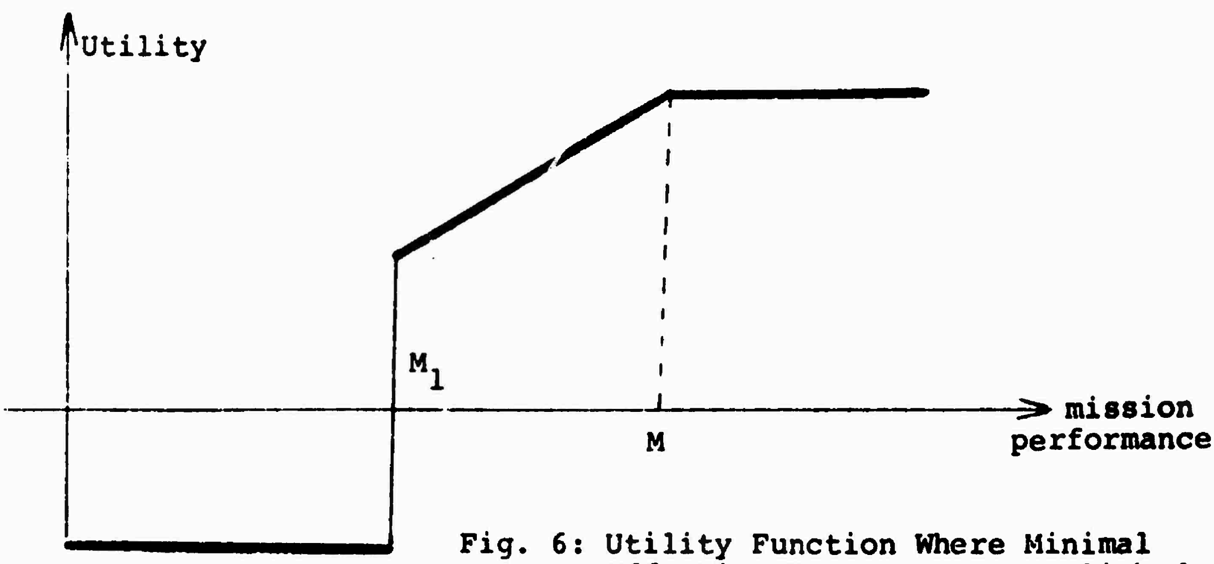

Fig. 6: Utility Function Where Minimal Effective Damage Is Accomplished at Level M_1 and Maximum at M

PROCEDURES FOR INTERVIEW APPROACH TO ESTIMATING UTILITY FUNCTIONS

The utility functions of Navy commanders and planners can be estimated by conducting a short personal interview with a sample of Navy personnel. This sample should be selected so that a cross-section of certain job-related characteristics are sufficiently represented in the chosen group of individuals. Some of these characteristics are mentioned in the section on Practical Aspects of the Methodology.

One plan could work as follows:

1. Sets of hypothetical operational mission scenarios are developed.

2. Each mission scenario will involve a task which must be accomplished together with possible alternate methods by which the task might be accomplished. The magnitude of the various resources which are most likely available to the decision-maker will be given.

3. The decision-maker will be informed that each possible method of task accomplishment involves certain risks. These risks will pertain to the possible losses of manpower and other resources, lack of accomplishment of either the entire mission or part of the mission, personal rewards or criticisms which may occur, and so on.

4. Given the above information, the decision-maker will be asked to respond to:

(a) his evaluation of his unit's readiness to perform the mission for each alternate method proposed.

(b) the reasons behind his readiness evaluations and, specifically, how they were influenced by the risk and uncertainty factors introduced.

(c) how changing the probabilities for the contingencies where risk and uncertainty exist would change his readiness evaluations. Changes in these probabilities will be proposed over a wide enough range to hopefully determine sets of indifference probabilities.

(d) whether he can suggest other methods of mission accomplishment such that he would consider himself more ready to accomplish the mission if he could proceed by these other methods, and why he would consider himself more ready.

In going about the above evaluations it is important to limit the mission scenarios to those within the experience of the commander. Thus, an officer who has had almost all his experience with submarine command would not be given scenarios involving destroyers.

Also in (c), since there can be many probability values given for any one alternative, the varying of the probability values for each to determine indifference sets has to proceed in a carefully controlled manner.

PRACTICAL ASPECTS OF THE METHODOLOGY

In attempting to measure attitudes towards risk and uncertainty of Navy operational commanders, it is instructive to examine other studies with other groups of individuals where similar attitudes were desired. Much of this work has been in agriculture [4], [5], geology [2], and forest management [7]. The difficulties encountered by these past studies can shed much light on the approaches which might prove most fruitful with Navy personnel, so we shall discuss some of them. One problem found in much of the past work relates to the fact that individuals often have great difficulty expressing their preferences among risky alternatives in terms of probabilities [3]. This is true even for students who have had formal training in probability and statistics. Thus, it seems important, when giving a subject a hypothetical risk situation upon which he has to express preferences, to avoid having to give probabilities as responses. This can be accomplished by stating the probabilities as some simple form of odds (such as a 50-50 chance of either A or B occurring) and requesting responses in terms of the variate of interest (dollars, time, number of ships lost, etc.). Secondly, most respondents quite correctly point out that there is a great difference in their attitudes, depending on whether it is their personal resources they are considering or whether these resources are those of an employer. Certainly, this problem will arise with Navy commanders where they, as others, may have difficulty in sorting out their personal and the organizational goals.

Third, respondents also point out correctly that their attitudes are influenced by time and by their financial situation at the point in time when they are asked about their attitudes and it is their own personal monetary goals which are involved.

When confronted with a decision-making problem involving several risky alternatives, a decision-maker will ordinarily be influenced, consciously or unconsciously, by two criteria:

(1) choosing the course of action which is best for the organization.

(2) choosing the course of action which is best for his own personal future.

There are several aspects of this which need discussion. First, it is not necessarily true that the choice indicated by criterion (1) is the same as that indicated by (2). The commander can rank these courses of action in his mind as to importance and this may become his basis for decision.

As an example of this situation, the shape of the decision-maker's utility function may have a low positive marginal utility for positive performance levels and a high positive marginal utility in the region of negative performance, as illustrated in Figure 7.

According to this function, the utility of increased performance does not rise significantly whereas the utility of increased levels of negative performance declines steeply as the negative performance increases. With such a criterion the decision-maker will tend to have a high degree of risk avoidance.

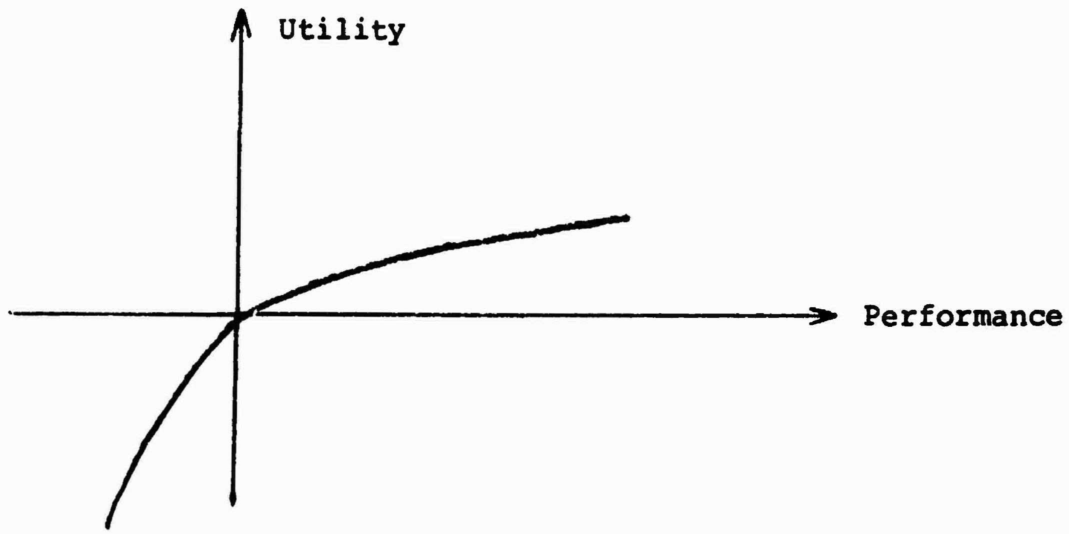

Figure 7. Possible Decision-Maker's Utility Function

(Of course, other utility function shapes are possible.) On the other hand, his perception of the Navy's attitude towards risk and uncertainty may be quite different.

Of course, in reality there is no such thing as a single utility function for the Navy. Commanders, depending on their rank, line or staff position, whether in operations or planning, etc., may have different concepts of what it is.

There are probably identifiable characteristics of commanders and planners which have to do with their Navy and other life experiences which will affect both their attitudes towards risky situations and their readiness evaluations. Examples of those which may prove significant are:

1. Combat experience
2. Length of time in present rank
3. Age
4. Nature of past personal experiences with risky alternatives

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